PUBLIC ROADS

A JOURNAL OF HIGHWAY RESEARCH

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

VOL. 18, NO. 11 ▽ JANUARY 1938

THE ANGEL OF SHAVANO, IN THE COLORADO ROCKIES

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PUBLIC ROADS ▸▸▸ *A Journal of Highway Research*

Issued by the

UNITED STATES DEPARTMENT OF AGRICULTURE

BUREAU OF PUBLIC ROADS

Volume 18, No. 11 January 1938

The reports of research published in this magazine are necessarily qualified by the conditions of the tests from which the data are obtained. Whenever it is deemed possible to do so, generalizations are drawn from the results of the tests; and, unless this is done, the conclusions formulated must be considered as specifically pertinent only to described conditions.

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PRESENT KNOWLEDGE OF THE DESIGN OF FLEXIBLE PAVEMENTS[a]

A REVIEW OF EXISTING DATA AND DISCUSSION OF NEEDED RESEARCH

BY THE DIVISION OF TESTS, BUREAU OF PUBLIC ROADS

Reported by A. C. BENKELMAN, Associate Research Specialist

DURING recent years highway engineers have become more and more interested in the problem of the design of flexible pavements. The reason for this interest is two-fold: First, because of the large mileages of this type of pavement that are built annually and the desire to build such pavements according to scientific principles; and second, because until accepted principles of design are formulated neither the question of the relative economy of different types of road surface nor the allied question of allocation of vehicle costs can be answered authoritatively.

The purpose of this report is to review the status of our existing knowledge of the problem and to point out what additional information is needed in order that dependable principles of design can be formulated. The report first reviews what is known about the design of the component parts of the road structure, continues with a discussion of the methods of design or formulas that have been suggested for determining the thickness of road surfaces, and concludes with a brief statement of the research aspects of the problem.

The statement has been made that the function of a pavement of the flexible type is to distribute the wheel load to the subgrade in such manner that the intensity of pressure will cause neither permanent nor elastic deformation of the soil of sufficient magnitude to produce failure of the pavement surface.[1] This means that primarily the subgrade and not the surface constitutes the medium of support of vehicular loads. Thus, knowledge of a quantitative character concerning the bearing capacity of soil materials when subjected to forces identical with those created by traffic loads is a first essential for the development of basic principles of flexible pavement design.

Great progress has been made during recent years in the study of soil science as related to the design and construction of highways. Certain basic facts established prior to 1930 led to the development ot ways and means for improving the stability of subgrade soils. For example, it was known that (1) the performance of a subgrade is governed by the physical characteristics of the soil, i. e., cohesion, internal friction, compressibility, elasticity, and capillarity, (2) these characteristics depend upon soil constituents which may be easily identified by laboratory tests, and (3) subgrades may be classified into groups on a basis of their physical characteristics.

SEVERAL METHODS CURRENTLY USED TO STABILIZE SOILS

In 1929 Hogentogler and Terzaghi[2] suggested an approximate method of analysis with which it was possible to develop some interesting data regarding the probable effect of the characteristics and condition of the soil on bearing power. They indicate in part that by combining a cohesive clay with a granular soil in the proper proportions, its bearing capacity could be more than tripled and, also, that the supporting capacity of a wet cohesive soil might be as low as one-thirtieth of the bearing capacity of the same soil when dry. The authors were able to demonstrate that the unit bearing capacity of a noncohesive soil increases with increase in the width of loaded area, and that the amount of increase is different in different soils. For soils entirely lacking in cohesion, computed values indicated that a marked increase in unit supporting capacity would accompany an increase in width of loaded area, whereas for cohesive soils no increase would be expected.

Methods employed at the present time for improving the stability of subgrade soils and foundation course soil mixtures are predicatd to a large extent upon the fundamentals enumerated above. They consist primarily of (1) soil stabilization wherein granular materials are added to cohesive soils or cohesive binder is incorporated with granular soils, (2) treatment with different materials such as deliquescent chemicals, bituminous products, or portland cement, and (3) installation of drainage structures or the construction of surface treatments which separately or jointly function to prevent cohesive soils from taking up moisture.

Recently other means have been developed for improving the stability as well as the permanency of support of subgrade soils. The work of R. R. Proctor[3] for example, indicates that for every soil there is an optimum moisture content at which maximum density can be obtained with a given method of compaction; and studies by Hans F. Winterkorn[4] point to the fact that the physical properties of a subgrade may be altered completely by chemical treatment of the soil.

The question of changing the characteristics of soils by artificial means has been touched upon here merely for the purpose of indicating that it is possible, on a basis of existing knowledge, to improve the quality, uniformity, and permanency of support of subgrade soils. The fact that the subgrade or the foundation course, which is generally composed of soil mixtures, plays such an important role in the performance of a flexible pavement emphasizes the need of designing these component parts of the structure in such manner

[a] Paper presented at the Seventeenth Annual Meeting of the Highway Research Board, Washington, D. C., 1937.

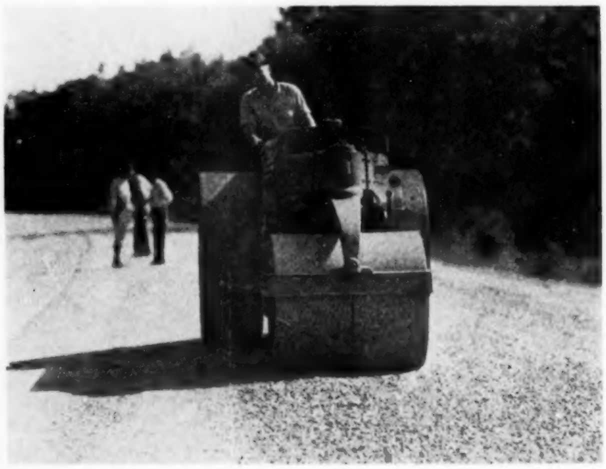
[1] A Symposium on Research Features of Flexible-Type Bituminous Roads, by E. F. Kelley. Part II. Proceedings of the Fourteenth Annual Meeting, Highway Research Board, 1934.

[2] Inter-relationship of Load, Road and Subgrade, by C. A. Hogentogler and Charles Terzaghi. PUBLIC ROADS, vol. 10, no. 3, May, 1929.

[3] Fundamental Principles of Soil Compaction. Engineering News-Record, vol. 111, no. 9, 1933.
Field and Laboratory Determination of Soil Stability. Engineering News-Record, vol. 111, no. 10, 1933.
Field and Laboratory Verification of Soil Stability. Engineering News-Record, vol. 111, no. 12, 1933.
New Principles Applied to Actual Dam Building. Engineering News-Record, vol. 111, no. 13, 1933.

[4] Oiling Earth Roads, Application of Surface Chemistry. Industrial and Engineering Chemistry, vol. 26, 1935.
Adsorption Phenomena in Relation to Soil Stabilization. Proceedings, Fifteenth Annual Meeting, Highway Research Board, 1935.
Surface Chemical Factors Influencing the Engineering Properties of Soils. Proceedings, Sixteenth Annual Meeting, Highway Research Board, 1936.

that they will provide uniform and constant support for the surface to be laid upon them. It is believed that this should constitute the basic procedure in design rather than to attempt to compensate for inequalities in foundation or subgrade support by varying the thickness of the surface crust. What appears to be needed at the present time is to translate the qualitative means available for improving subgrade support into quantitative values suitable for use in a mathematical treatment of the problem.



ROLLING A SURFACE-TREATED ROAD SERVES TO COMPACT THE SURFACE INTO A DENSE MASS, INCREASING ITS LOAD-CARRYING CAPACITY.

BEARING CAPACITY OF A SOIL DEPENDS UPON SEVERAL VARIABLES

Most of the existing test data on soil bearing power have been developed from studies of the design of foundation footings. Here, in marked contrast to subgrades for flexible pavements, the pressures imposed upon the soil medium are of the sustained type and are of practically uniform intensity. Whether either the test data or the theoretical conceptions of bearing power that have been developed from these studies are applicable at all to the problem under discussion depends, in part at least, upon whether the static wheel load proves to be the critical load for which the thickness of pavement surface must be designed.

If it is found that the action of the rolling wheel load plus the impact effect of a motor vehicle is, under average conditions, more severe than that of the static wheel load, then it would appear that our present knowledge of soil-bearing power has little application in the design of flexible pavements. If, on the other hand, future investigations should show that the combined effect of the moving wheel and impact is less severe than that of the static load alone, then these data should prove of value and the logical procedure would be to base the design or thickness of flexible surfacings upon the static wheel load.

This question is one of the most controversial issues that has entered into attempts to develop a rational method of design on a basis of our existing knowledge. In some of the suggested methods of design there is an allowance for the dynamic effect of moving vehicles of as much as 50 percent over and above the permissible static wheel load, whereas in others no allowance whatever is included.

Space does not permit, nor do the circumstances appear to warrant, a detailed review in this report of the existing data on soil bearing power. An attempt will be made, however, to discuss the problem in a general way and to cite some of the more significant results of the many investigations and analyses that have been made.

It was indicated previously in connection with the approximate method of analysis by Hogentogler and Terzaghi that the bearing capacities of soil media depend upon the size of the loaded area, and that the degree of this dependence is determined by the characteristics of the material. The question of variation in bearing capacity with size of loaded area is an important one, as far as flexible pavements are concerned, because the areas of subgrade pressure lie within the size range in which, according to existing test data, the most marked variations in bearing capacity are encountered.

A great number of investigations have been made concerning the bearing capacities of soils of a cohesive nature. Most of them involved the application of sustained loads to the soil material through rigid bearing plates which ranged in size generally from a few square inches up to 9 square feet. The results obtained, including those of Stötzner in 1919,[5] A. Bijls in 1923,[6] the Bureau of Public Roads in 1925[7] and Fritz Emperger in 1926,[8] indicate that the unit bearing capacity of such soils for a given settlement decreases as the size of the loaded area increases and that settlement under the same unit load varies almost directly as the square root of the area. W. S. Housel in 1929[9] in a series of tests that involved several types of cohesive soil found also that for a given settlement the larger the area the smaller the unit bearing capacity. In general, as far as the effect of size of loaded area is concerned, the data he obtained are in agreement with those of the other investigators mentioned above.

In Germany the bearing capacity of soils has been studied quite extensively in recent years. While the majority of tests made have involved soils which, as far as it has been possible to ascertain, might be said to fall on the border line between those of a cohesive and noncohesive nature, the results are of considerable interest. The conclusions reached in these researches indicate, in general, that (1) the unit bearing capacity varies with the size of loaded area, (2) settlement consists of both elastic and permanent compression of the material, and (3) lateral displacement of the soil from beneath the loaded area, particularly in small-sized areas in conjunction with excessive unit pressures, is an important contributory factor to settlement.

EFFECT OF SIZE OF LOADED AREA ON BEARING CAPACITY STUDIED

E. W. Goerner,[10] working in the soils laboratory of the Freiberg Institute under the direction of Dr. Kögler, studied in great detail the load reaction char-

[5] Erzielung gleicher Fundamentsenkung durch wahl des kleineren Bodeneinheitdruckes bei der grössern Fundamentfläche. Dissertation, Braunschweig, 1919.

[6] Le Genie Civil, May 1923, pp. 490–492.

[7] The Supporting Value of Soil as Influenced by the Bearing Area, by A. T. Goldbeck and M. J. Bussard. PUBLIC ROADS, vol. 5, no. 11, January 1925.

[8] Die zulassige Belastung des Baugrundes. Die Bautechnik, vol. 4, 1926.

[9] A Practical Method for the Selection of Foundations Based on Fundamental Research in Soil Mechanics. Department of Engineering Research, University of Michigan. Bulletin No. 13, 1929.

[10] Über den Einfluss der Flächengrösse auf die Einsenkung von Gründungskörpern. Geologie und Bauwesen, no. 3, 1932.

acteristics of a natural sand soil. Static loads were applied to material held in box containers, through circular, rigid bearing plates which ranged in area from 5 square centimeters to 1 square meter (0.775 sq. in. to 10.8 sq. ft.). The containers were of sufficient size and depth to eliminate confining effects. The material in an artificially dried state was placed in the containers with a given degree of compaction for each individual test.

A great number of tests were made, the results indicating rather definitely that the effect of size of loaded area depends, among other things, upon the unit pressures imposed on the material. For very low unit pressures settlement was practically independent of size of area, irrespective of the density of the material. For larger unit pressures, beginning with an area of approximately 75 square inches, the settlement increased as the bearing area was either decreased or increased. According to Goerner, the behavior in the first instance was caused by lateral displacement of the material from beneath the loaded area and, in the second, chiefly by vertical compression which increases as the size of the area increases. The rate of increase of settlement with decreasing area is rapid for, as the area approaches a minimum size, "pile action" apparently develops. The rate of increase of settlement with increasing size of area is more gradual, the data in general indicating that the increase varies almost in direct proportion with the square root of the loaded area.

Goerner's tests were made in the laboratory under carefully controlled conditions. As far as the effect of size of bearing area is concerned, the results as described were definite and conclusive. Heinrich Press [11] in studying the bearing capacity of soils in the field obtained results that are in close agreement with those of Goerner. Most of his work was done in connection with the design of foundations, the tests of bearing capacity of a number of types of soil being followed with observations of settlement of the structures erected. In general, the results of these studies indicate that the settlement of structures cannot be predicted with any great degree of certainty from the behavior of small-sized test areas, particularly for structures resting on soils of a sandy nature.

Recently the Bureau of Public Roads has investigated the bearing capacity of a silt loam soil beneath rigid bearing plates ranging in size from about 3 square inches to 38 square feet, the latter area being nearly four times larger than that used in any of the tests mentioned above. The tests indicate clearly that for areas less than about 5 square feet, the settlement under the same unit load was proportional to the diameter or the square root of the area. For areas exceeding this size, however, the results of the tests showed the settlement to be independent of the size of the bearing area.

The tests were made in connection with an investigation of concrete pavement design, their purpose being to determine the modulus of subgrade reaction in order that measured slab stresses might be compared with those computed by means of Westergaard's theory of slab stress. Because rigid pavement slabs are subject to but very small deflections, the tests were limited, in general, to settlements of a magnitude considerably less than those of the other studies enumerated.

[11] Baugrundprobebelastungen, ihre Auswertung und die an den Bauwerken gemessenen Setzungen. Die Bautechnik, vol. 10, no. 30, 1932.

RELATIONS BETWEEN SETTLEMENT AND SIZE OF LOADED AREA GIVEN FOR COHESIVE AND NONCOHESIVE SOILS

From what has been presented in the preceding paragraphs, it is apparent that our knowledge of soils has advanced to the point where the bearing power of subgrades can be improved in a scientific manner. By the incorporation of granular materials in clay soils or by furnishing granular soils with cohesive binder, they can be improved with respect to both the quality and uniformity of support. By treatment with deliquescent chemicals, the moisture content of graded soil mixtures can be controlled and their supporting power maintained within fairly narrow limits. Soils of defective grading may also be improved by admixtures of bituminous materials or portland cement. In addition to these methods, which are in general use at the present time, the more recent discoveries involving compaction of soils at their optimum moisture content and base exchange by chemical treatment offer further possibilities for improving the support of subgrade soils.

The proponderance of existing test data on soil bearing power indicate that (1) the settlement of cohesive soils under the same unit load varies directly as the square root of the area, and (2) the settlement of noncohesive soils under the same unit load for very low pressures is independent of size of area. As the unit pressure on noncohesive soils is increased, beginning with an area of approximately 75 square inches, settlement increases as the size of area either decreases or increases from this value; as the area increases, settlement increases almost in direct proportion to the square root of the area; as the area decreases settlement increases, at first gradually, then rapidly.

The above generalization relating to cohesive soils is applicable only for pressures which lie well within the safe bearing capacity limits of the material and for areas up to approximately 9 square feet, the maximum size of area used in the majority of tests made. The generalizations for noncohesive soils apply for areas up to about 1 square meter (10.8 square feet).

The test data developed recently by the Bureau of Public Roads in connection with the concrete pavement studies are in disagreement with the above-stated relationship between settlement and loaded area for cohesive soils. In these tests, settlement under low unit pressures, for areas up to about 5 square feet, varied directly as the square root of the area; and for areas above this size up to a maximum of 38 square feet, resistance was indicated to be independent of size of area. Inasmuch as these tests were made with care and precision, there is no reason to doubt that the results reflect the true area-settlement reactions of this particular soil medium. Why the results fail to agree with the other test data cited to the extent above indicated is not known.

Obviously the true influence of the size of bearing area for a particular grade of soil cannot be determined by test unless the material in question is perfectly homogeneous to a depth at least equal to that to which the effect of the load extends. It is the exception rather than the rule to find such homogeneity in soils as they exist in nature, and it is largely for this reason that the results of bearing-capacity experiments on areas of test size cannot always safely be extended to pressure areas of a size such as are found beneath foundation footings or even rigid pavements.

Beneath flexible pavements, pressure areas on the subgrade resulting from loads on the surface will tend

to be small and, in general, may not exceed 10 square feet. This does not mean, however, that the penetration-area relationship suggested by the preponderance of existing test data is applicable to the problem of design of such pavements. In the first place, the test data cited were developed using rigid bearing plates; and in the second place, with possibly one exception, the material surrounding the loaded area was not restrained from movement in any way. Conditions are quite different in flexible pavement subgrades because the wheel load is transmitted to the soil through a flexible medium whose weight serves to increase the resistance of the soil to lateral as well as upward movement.

FEW DATA AVAILABLE ON PRESSURE DISTRIBUTION UNDER FLEXIBLE PAVEMENTS

Few attempts have been made to develop comprehensive data on either the load reaction characteristics of flexible pavements or the manner in which they distribute loads to the subgrade. The reason for this probably lies in the difficulty of developing satisfactory apparatus and testing technique rather than any lack of interest in the subject. However, even with the somewhat crude methods employed at the time of the Bates Road tests [12] and by the Bureau of Public Roads in 1923,[13] information of interest and of value was produced.

When the Bates road was built, a total of 26 pressure cells were installed on the subgrade of certain of the sections. Tests were made subsequently, involving study of the deflection of the surface and pressure distribution on the subgrade as a loaded truck was moved slowly toward and away from the points where the cells were located. While only a single cell was installed on the subgrade beneath a flexible pavement section (sec. 5—3-inch brick, 2-inch mastic cushion, 8-inch rolled stone base) data obtained during the limited tests made are of interest.

Before subjecting the test road to truck traffic, a 4-ton wheel load produced a maximum pressure of 12 pounds per square inch on the subgrade. After 1,000 trips of the 2,500 pound wheel-load increment of loading the pressures produced by the 4-ton static wheel load amounted to 30 pounds per square inch. Apparently the mechanical bond existing in the rolled stone base course had been at least partially destroyed by the disruptive action of the moving trucks. This would decrease the area over which the static wheel load was distributed to the subgrade and thus increase the unit pressure.

The tests by the Bureau of Public Roads in 1923 involved the application of sustained loads, through a bearing block shaped to simulate a truck wheel, to layers of crushed stone of several thicknesses laid both upon a dry sand and a wet clay supporting medium. The distribution of the loads through the materials was measured with pressure cells placed both on and beneath the soil layers. These tests indicated that (1) under a given load the maximum intensity of pressure decreases as the thickness of surface increases, the decrease being, roughly, directly proportional to the increase in thickness; (2) in general, the thicker the surface the higher the load-carrying capacity; (3) the thicker the surface, the higher the intensity of pressure on the subgrade can be, at least until failure begins to take place; and (4) the more resistant the supporting medium, the higher the intensity of pressure developed and the greater the ratio between the maximum and average pressures.

In 1924 the Bureau of Public Roads [14] studied the bearing capacity of a number of gravel roads in Minnesota. The surfaces ranged in thickness from 6 to 12 inches and all were on the same general type of subgrade. Static loads were applied to the surface crust through a rectangular-shaped bearing block, 52 square inches in area. The tests indicated that:

1. Settlement was almost directly proportional to load.
2. Resistance of the surfaces was high; four out of six locations supported a load of 100 pounds per square inch at a settlement of 0.10 inch.
3. The effect of the loads was confined practically to the area beneath the bearing block, deflection gages placed 6 inches away registering no movement.
4. At one location after loading the surface the gravel course was removed and the subgrade soil loaded directly. For equal settlements up to 0.10 inch the subgrade supported only about one-half the unit load carried by both the surface (6-inch thickness) and the subgrade.

Tests made in 1928 [15] by the Bureau of Public Roads throw some light on the possible difference in impact reaction of flexible as compared to rigid pavements. It was observed that a flexible pavement consisting of a 1-inch sheet asphalt wearing course on a waterbound macadam base deflected over an appreciable area under an impact load and then sprang back without apparent injury. The deflection at the point of application of the load amounted to as much as ½ inch, some deflection being noticeable at a point 3 feet away. In several rigid pavements, which were subjected to the same test, the deflection was much smaller and the impact reaction higher.

VARIATION IN PRESSURE UNDER BEARING PLATES OF DIFFERENT RIGIDITY DISCUSSED

A great amount of investigation and study has been given to the problem of pressure distribution in soils in connection with the design of foundation structures. Here pressures are transmitted to the soil through bodies which, in contrast to flexible pavement surfaces, are essentially rigid in character. Some work carried on in Germany indicates the difference in the pressure distribution as well as the supporting capacity of soils when loaded through bearing plates whose degree of rigidity was varied between rather wide limits.

Kögler and Scheidig [16] in a series of tests studied the pressure distribution in sand when sustained loads were applied to the material through three bearing plates, centrally loaded. All were 99 centimeters (39 in.) in diameter, but varied greatly in rigidity. At a depth of 40 centimeters (15.75 inches) the maximum pressure amounted to 103, 153, and 181 percent of the applied unit pressure for rigid, semirigid, and elastic plates, respectively. At a depth of 10 centimeters (3.94 inches) the maximum pressure amounted to 160 and 300 percent of the applied unit pressure for the rigid and

[12] Bates Experimental Road, by C. Older. Bulletin No. 18. State of Illinois, Division of Highways, 1924.

[13] Highway Engineering Investigations at the Arlington Experiment Farm, by A. T. Goldbeck. Proceedings Ninth Annual Conference on Highway Engineering, University of Michigan, 1923.

[14] Unpublished data of the Bureau of Public Roads.

[15] Effect of Pavement Type on Impact Reaction, by J. T. Thompson, PUBLIC ROADS, vol. 9, no. 6, August 1928.

[16] Druckverteilung im Baugrunde, F. Kögler and A. Scheidig. Die Bautechnik. No. 31, July 15, 1927.

flexible plates, respectively, no value being given for the semirigid plate. As was to be expected, the greater the rigidity of the bearing plates the less the variation in unit pressure under the plates.

Additional information on the same subject was developed by Heinrich Press in 1934.[17] Sustained loads were applied to two types of soil through square bearing plates of different rigidity, the pressure being recorded in the material at depths of 10, 32, 54, and 76 centimeters (3.94, 12.6, 21.3, and 29.9 in.). The vertical displacement of the plates was recorded also, both at the edge and center. One of the soils was the same as that used in the tests by Kögler and Scheidig, the other being described as a loam containing 21 percent sand. Tests were made on the latter material both in the dry state and when containing 32 percent moisture.

The results of the tests are summarized in table 1. These data indicate clearly that the maximum pressure that may develop at some depth in a soil from the application of an external load depends to a marked degree upon the flexibility of the body through which the load is transmitted.

TABLE 1.—*Results of sustained load tests on different soils using bearing plates of different rigidity*

Soil	Maximum soil pressure—10 cm (3.94 in.) beneath surface—expressed in terms of applied unit load					
	60 by 60 cm (23.6 by 23.6 in.) plates			50 by 50 cm (19.7 by 19.7 in.) plates		
	Rigid	Flexible—1.5 mm (0.059 in.) steel		Rigid	Loaded at center	
		Loaded at center	Loaded uniformly		Semirigid (0.0787 in.) 2.0 mm steel	Flexible (0.059 in.) 1.5 mm steel
Sand	1.36	3.05	1.50	1.50	2.95	3.30
Loam, dry	1.35	2.90	1.09	1.49	2.80	3.14
Loam, moist	1.26	3.00	1.50	1.50	2.98	3.20

USE OF OSCILLATING MACHINE IN STUDY OF PAVEMENTS DESCRIBED

With regard to the displacement or settlement of the soils, only limited data in graphical form are given in the report. In case of the rigid 60- by 60-centimeter bearing plate on the sand, the settlement amounted to about 0.2 centimeter, and for the flexible plate loaded at the center with the same apparent unit load it amounted to approximately 2 and 1 centimeters at the center and at the edge, respectively. For the rigid plate on the dry loam, the settlement was about 0.3 centimeter and for the centrally loaded flexible plate the settlement at the center was about 1.5 centimeters. For the flexible plate, uniformly loaded on the sand, the average settlement was about 0.7 centimeter and on the moist loam about 0.5 centimeter. It is of interest to note from the graphical data given in the report that the sand beneath the rigid plate supported with considerably less settlement a unit load 2.5 times greater than that which it supported when beneath the flexible plate. Comparable data for the loam soil are not given.

Recently a comparatively new method of test has been used in Germany to study the load reaction characteristics of soils and road surfaces. The method, briefly described, involves the application of periodic forces, the intensities of which vary according to a sine law, to a material and the study of its physical reaction by measurements of displacement and speed of propagation. An oscillating machine is used to apply the forces. It consists essentially of two parallel shafts that rotate in opposite directions and to each of which is attached an eccentric weight. The weights are so synchronized that, as they revolve, only vertical reactions are developed.

The displacement of the soil medium or road surface under the action of this machine is measured at successive distances from the center of force application by means of precise, electrically operated seismographs. The same instruments are used also to record the rate at which a given force impulse is propagated in the medium.

A great amount of work has been done in the development and standardization of this method of test. First, it was used for studying the effect of vibrations in buildings and other structures and later for investigating the physical properties of soils. During the past few years, it has been used to study the properties of both flexible and rigid pavements when acted upon by dynamic forces.

One investigation of unusual interest was carried on at Stuttgart, Germany, under the direction of F. J. Meister.[18] The purpose of the investigation was primarily to evaluate the intensity of the forces imposed upon flexible pavements by moving vehicles. To do this it was first necessary to develop quantitative values that would indicate the ability of such pavements to support loads of a dynamic nature. This information was developed with the oscillating machine and displacement recording instrument. The machine was operated at different frequencies and at different load intensities on the surface of the road and the displacement of the pavement in a vertical and in two horizontal directions was measured.

Tests of this general nature were made on four flexible pavements and on one rigid pavement. Subsequently trucks, both empty and loaded, equipped with different types of tires were operated at various speeds over the surface of one of the flexible pavements and the displacement of the surface again recorded. The displacement values were then converted to kilograms of dynamic force.

EFFECT OF DYNAMIC LOAD MEASURED BY OBSERVING PAVEMENT DEFLECTIONS

Inasmuch as the size and contact area of the tires used in the moving load tests varied over rather wide limits, it was necessary in the preliminary tests with the oscillating machine to investigate the effect of size of the contact area on which the dynamic load was applied. The results obtained from a limited series of tests involving the application of the same force intensity at several frequencies through the normal machine contact area (1,220 sq. cm, 78.7 sq. in.), and through an area about one-tenth of this size indicated no consistent or appreciable difference in effect.

It is true that one might well question whether the effect of loads of either a static or dynamic nature, on flexible pavements, can be measured accurately by displacement observations made either at the point where

[17] Druckverteilung unter starren und elastischen Lastflächen verschiedener Grösse bei verschiedenartiger Belastung im Sand und Lehm. Die Bautechnik, No. 43, October 5, 1934.

[18] Die dynamischen Eigenschaften von Strassen. Dissertation. Martin Boerner, publisher, Halle (Saale), Germany. 1936

the load is applied or at some distance from this point. In the above-mentioned tests the conclusions as to relative effect were based on the vertical displacements measured at a distance of 0.4 meter from the point at which the load was applied.

Two separate and distinct series of tests using moving loads were made, one with the trucks traveling over the natural surface and the other with the wheels on one side of the vehicle passing over an obstruction 1 inch in height at the point where the displacement of the surface was recorded. The results of the tests, which are shown both in graphical and tabular form in the report, indicate in general that (1) on a flexible pavement of normal and uniform smoothness, the intensities of the dynamic loads vary in almost a direct proportion with vehicle speed, (2) the magnitude of the sprung load has very little effect upon the intensity of the resulting force.

When the artificial obstruction was employed the data indicate that for a given tire type the same dynamic effect was developed with a wheel load of 2,100 kilograms (4,620 pounds) as with one of 1,350 kilograms (2,970 pounds). The indicated dynamic force was 2,500 kilograms (5,500 pounds) for both wheel loads when solid-rubber-tire equipment was used and 1,000 kilograms (2,200 pounds) with pneumatic tire equipment.

With the truck traveling over the normal road surface, the same wheel loads equipped with solid tires produced dynamic forces of 575 kilograms (1,265 pounds) and 500 kilograms (1,100 pounds), respectively, while with pneumatic tires the indicated forces were 250 kilograms (550 pounds) and 175 kilograms (385 pounds), respectively.

It is difficult to reconcile the force values obtained by this method of test with the results of the motor-vehicle impact studies made in this country. In this connection Meister is not specific in stating whether his dynamic force values are to be interpreted as representing the dynamic increments alone or the total forces developed by the movement of the vehicles over the road surface.

Earlier in this report attention was called to the fact that as yet we do not know whether the thickness of flexible pavements should be based on the static or dynamic wheel load. Not only is adequate information lacking concerning the intensity of the dynamic wheel load on the average flexible pavement but we know very little of the effect such a load has upon the structure as compared to the static wheel load. According to Meister, it would be a simple matter to develop quantitative data regarding the ability of flexible pavements to support moving vehicular loads by means of the oscillator method of test. He states that, "* * * for low frequencies of vibration or low rates of load application, the load-displacement values constitute an index of the dynamic modulus of pavement reaction * * *;" i. e. the force necessary to displace 1 square centimeter of the surface to a depth of 1 centimeter.

Certainly the development of such data by any method of test for pavements of various thicknesses laid upon the same and different subgrades would prove of great value in establishing basic principles of flexible pavement design.

STRESSES INDUCED IN PAVEMENT BY OSCILLATING MACHINE COMPUTED

Dr. A. Ramspeck, at present a member of the staff of the German Research Society of Soil Mechanics, has carried on some work with the oscillator method of test which suggests the possibility of developing information of interest and value concerning the dynamic properties of concrete pavements.

One of the first facts established in studies of the dynamic properties of soils with an oscillating machine was that the rate at which a quickly applied force is propagated in a soil medium depends upon the elastic properties and possibly upon other physical characteristics of the soil. Such a force sets up vibrations in the medium, the propagation of which takes place in the form of waves whose length is a function of the speed of movement, low speeds being characterized by short wave lengths, high speeds by long wave lengths. From this it would appear that the higher the propagation speed of dynamic waves in road structures, the less severe the vibratory disturbances would be.

The tests by Ramspeck[19] were predicated in part upon these considerations. Besides investigating the rate at which oscillator force impulses were propagated in concrete pavements of various thicknesses laid upon different types of subgrade, he measured the amplitudes of slab movement at different points. From the data obtained he developed the deflection profiles of the slab existing at any given instant. Since an oscillating machine was used to apply the forces, he assumed the vibrations were sine-shaped and on this assumption developed mathematical relations by means of which the bending stresses in the concrete were computed.

In one set of tests, Ramspeck, in the manner described above, computed the vibratory bending stress in slabs of the same thickness (25 cm.) laid upon three types of subgrade: (1) Poor-quality sand; (2) loam soil on which a sub-base of crushed stone 7 centimeters thick was placed, and (3) high-quality rolled gravel. The same force intensity was applied to all three slabs at a frequency of 25 cycles per second. The computed values of slab stress as given in the report amounted to 0.074, 0.014 and 0.007 kilogram per square centimeter (1.0, 0.20, and 0.10 lb. per sq. in.), for bases (1), (2) and (3), respectively.

In connection with these tests, sine wave profiles of the slabs, reproduced from the seismograph records, are shown in the report. These are interesting inasmuch as they show the differences in wave length and amplitude of movement that were observed with the three test slabs. The wave length for the test slabs on subgrades (1) and (2) was about 10 meters, while that of the slab on subgrade (3) was in excess of 20 meters. The amplitude of vibratory movement, in contrast to the wave lengths, was nearly the same for slabs on subgrades (2) and (3) (0.0010 to 0.0012 mm), while for the slab on the poor sand subgrades the amplitude was 0.006 millimeter.

OSCILLATING MACHINE USEFUL IN PRODUCING REPEATED DYNAMIC FORCES OF KNOWN MAGNITUDE

Ramspeck also investigated the action of joints in concrete pavements when the structure was set in vibration with an oscillating machine. In one series of tests he measured the amplitude of movement at six points, three on one side of a longitudinal joint and three on the other, the slab in question being laid upon a compacted gravel subgrade. The joint was of the dummy type, a groove 6 centimeters deep being cut into the surface with a special joint-cutting machine.

[19] Dynamische Untersuchungen auf Strassendecken. Die Beton-Strasse, No. 2, 1936.
Praktische Anwendungen dynamischen Untersuchungen Veröffenentlichungen des Instituts der Deutschen Forschungsgesellschaft fur Bodenmechanik (Degebo) an der Technischen Hochschule, Berlin. Heft. 4. Julius Springer, publisher. 1936.

The presence of this groove in the surface did not in any way serve to disturb the continuity in vertical movement of the slab. In another series of tests the vertical displacement of a pavement laid on a yielding subgrade and containing transverse joints was measured out to a distance of 60 meters from the point where the force impulses were applied. In these tests the continuity of the displacement or deflection curve was broken at each of the joints.

Ramspeck explains these phenomena as follows: A subgrade whose elastic properties or physical characteristics tend to approach those of the surfacing material will vibrate in harmony with the surface and the two media will tend to respond as a unit to vibratory motions. On the other hand, a subgrade whose physical characteristics differ to a marked degree from those of the surfacing material is apt to vibrate out of harmony with the surface. In other words, a sharp plane of discontinuity, at least as far as vibratory movements are concerned, may or may not exist between the road surface and supporting medium.

By studying the rate at which oscillator force impulses are propagated in road bodies before and after laying concrete pavements, information was developed which, according to Ramspeck, may be used to indicate the thickness of slab necessary on new construction work. For example, according to graphical data shown in his report, a slab 25 centimeters in thickness would be necessary on a subgrade having a propagation speed of 125 meters per second (410 ft. per sec.), one 20 centimeters in thickness for a speed of 210 meters per second (690 ft. per sec.), and one 15 centimeters in thickness for a subgrade whose propagation speed is 250 meters per second (820 ft. per sec.).

In connection with these particular data, Ramspeck infers that it should be possible to develop information concerning the proper thickness of pavements of the flexible types for different subgrades from measured values of propagation speed.

The above constitutes only a very brief résumé of the dynamic method of test. The results of certain investigations have been cited not because they are considered highly significant or conclusive, but primarily for the purpose of illustrating the type of information concerning the dynamic and vibration properties of road structures that may be developed with this method of test.

The fact that repeated dynamic forces of known magnitude and characteristics can be applied to a road structure with an oscillating machine is one of the strongest arguments in favor of this method of testing. It should be possible with such a machine to apply forces that are similar in character to those which are imposed upon pavements by moving vehicles inasmuch as the revolving eccentric weights are analogous to the unsprung mass of a vehicle and the weight of the machine is analogous to that of the sprung load. The obvious advantages gained from the use of such a machine in pavement design studies instead of moving vehicles are: (1) The magnitude of the forces can be definitely controlled and determined, and (2) the same intensity of force can be applied and repeated at any desired point and at a range of rates of application.

FORMULAS FOR COMPUTING THE THICKNESS OF FLEXIBLE PAVEMENTS DISCUSSED

As early as 1901, consideration was given to the possibility of designing flexible pavements according to scientific principles. At that time what is now known as the Massachusetts' rule was evolved. This rule states that "the pressure is distributed through macadam and any ordinary gravel or boulder base at an angle of 45° with the horizontal, and the resulting maximum pressure (P) on the subgrade amounts to the wheel load (W) divided by the square of twice the thickness (T) of pavement." This rule may be expressed algebraically as follows:

$$P=\frac{W}{(2T)^2} \text{ or } T=0.5\sqrt{\frac{W}{P}}$$

One of the questions considered at the Third International Road Congress (held in 1913) concerned the design and construction of water-bound macadam roads. Of eight reports dealing with this question presented at the meeting, that of Charles Lelievre [20] is most interesting and constructive. In reading the report one cannot help but be impressed with the fact that the author had a broad perspective of the problem in general and an appreciation of the need of designing roads according to scientific principles.

After discussing the function of the different component parts of the road structure he commented on the fact that there is an undeniable relationship between subgrade support and foundation and wearing course thickness that should be considered in the rational economic construction of a road. He called attention to the need for conducting experiments to determine the area over which traffic loads are distributed in road surfaces and for finding out what intensities of pressure are transmitted through the surface and foundation course to the subgrade. Lacking such data, by resorting to the use of information developed in 1877 by Leger in the course of a study of the distribution of forces in solid bodies conducted by means of polorized light, Lelievre attempted to obtain a solution to the problem of load distribution in road surfaces.

From his analysis he concluded that:

> When the upper surface of a road is pressed vertically by a force covering an area of diameter d the extreme lines of pressure in the interior of the road assume the form of a bell, having their apex within d and embracing at the lower base of the surface a zone of diameter D such that the difference $D-d$ does not exceed 2½ times the thickness of the surface.

For foundation course mixtures he decided for reasons not stated that the difference $D-d$ should not exceed 1½ times the thickness of the course.

Using these relationships, Lelievre made a series of calculations that served to indicate the intensity of pressure that would be apt to develop on the subgrade beneath road surfaces of different thicknesses. The results of his calculations, for an assumed load of 8,816 pounds resting upon the rim of a wheel 5.51 inches wide are given in table 2.

The relationships used by Lelievre may be expressed algebraically as follows:

For surface courses

$$P=\frac{W}{\pi(2.5T+d)^2/4}$$

For foundation courses

$$P=\frac{W}{\pi(1.5T+d)^2/4}$$

[20] Construction of Water-bound Macadamized Roads. Proceedings, International Road Congress. Report No. 81. 1913.

TABLE 2.—*Calculated intensity of pressure on the subgrade caused by a load of 8,816 pounds*

SURFACE COURSES						
Thickness, inches	1.97	3.94	5.91	7.87	9.84	11.81
Subgrade pressure, pounds per square inch	102.5	47.7	27.4	17.4	12.3	9.1
FOUNDATION COURSES						
Thickness, inches	5.91	7.87	9.84	11.81	15.74	39.37
Subgrade pressure, pounds per square inch	56.0	37.4	27.2	20.7	13.4	2.7
COMBINED SURFACE AND FOUNDATION COURSES						
Thickness of foundation course, inches	5.91	7.87	9.84	11.81	27.56	39.37
Subgrade pressure, in pounds per square inch, for surface courses of:						
3.94 inches	19.3	14.7	12.6	10.2	3.5	2.0
5.91 inches	13.2	10.9	9.1	7.7	3.1	1.7
7.09 inches		9.1				
7.87 inches	9.7	8.2	6.8	6.1	2.8	1.6

In which P = the unit pressure on the subgrade.
W = the applied wheel load.
T = the thickness of surface.
d = diameter of the load contact area.

In using these equations for computing the subgrade pressure beneath a pavement consisting of a surface and foundation course, it is necessary first to solve for the value of D for the surface course ($D=2.5T+d$) and substitute this value of D for d in the second formula.

MIXING OIL-TREATED GRAVEL IN THE CONSTRUCTION OF A FLEXIBLE-TYPE ROAD SURFACE. THE RESISTANCE THAT THIS TYPE OF SURFACE OFFERS TO DEFORMATION UNDER LOAD DEPENDS ESSENTIALLY UPON THE DEGREE OF COHESION AND INTERNAL FRICTION IT POSSESSES.

DISCUSSION OF OTHER FORMULAS

With regard to the values given in the table, attention is called to the fact that they have been referred to and accepted in this country as data derived from actual tests. The facts of the situation may be summed up as follows: A Mr. Washington who attended the Third International Road Congress as a delegate from New York State, in reporting his trip to the State Highway Commissioner,[21] listed the French pressure values with the comment:

> Very interesting to us are French tests of the amount of pressure exerted through the road on the subsoil by a wheel load of 4 tons with a 5.5-inch tire.

The data were reproduced subsequently in Engineering and Contracting (vol. 42, December 16, 1914) with the statement that:

[21] Report of the State Commissioner of Highways (New York), 1913, vol. 2.

> The following notes on the transmission of pressure through macadam to the subgrade were made by W. de H. Washington in the last annual report of the New York Highway Commission * * *. French tests on the amount of pressure exerted through the road on the subgrade by a wheel load of 4 tons * * * gave the following results * * *.

Two years later the values appeared in Agg's 1916 edition of Construction of Roads and Pavements. In 1927 Harger and Bonney [22] proposed a method of design for flexible pavements. In a discussion of the method they not only call special attention to the fact that their formula for thickness is in essential agreement with the French test data of Lelievre, as reproduced by Agg, but they also show the comparison in graphical form.

The Harger and Bonney formula is predicated upon the Massachusetts rule of pressure distribution at an angle of 45°, although it is modified slightly so as to permit taking into consideration the width of tire through which the load may be applied to the road surface. Expressed in terms of thickness, it is as follows:

$$T=\sqrt{\frac{W}{3p}+\frac{a^2}{9}}-\frac{a}{3}$$

In which T = the thickness of surface.
W = the load.
p = the unit pressure on the subgrade.
a = width of tire.

B. E. Gray [23] has suggested a formula of the same general type for figuring the thickness of flexible pavements. It takes into consideration the area rather than the width of tire contact as follows:

$$T=0.564\sqrt{\frac{W}{p}}-\frac{d}{2}$$

In which T = thickness of surface.
W = the load.
p = the unit pressure on the subgrade.
d = diameter of equivalent area of tire contact.

The above formulas assume that all types of flexible pavements will transmit superimposed loads to the subgrade at a definite and constant angle with the horizontal and that the pressure transmitted to the subgrade is uniform over the area affected. In view of these assumptions it is not surprising that so little consideration has been given to their use as a means of determining the necessary thickness of surface on new construction work.

It is a matter of common knowledge that the resistance that a bituminous or soil-aggregate mixture offers to deformation under load depends essentially upon the degree of cohesion and internal friction it possesses. Certainly if variations in these properties affect resistance they in turn will affect load distribution since resistance and load distribution are closely related. Moreover, it is known that the intensity of the pressure imposed upon the subgrade will vary, depending upon such factors as the character of the soil material and the flexibility of the surface through which the loads are transmitted.

[22] Highway Engineers Handbook, Harger and Bonney, vol. 1, Fourth Edition, 1927.
[23] The Design and Construction of Bituminous Pavements. Report presented at the Annual Meeting of Highway Engineers and Commissioners of Michigan, Houghton, Mich., 1934.

THE WELL-DESIGNED FLEXIBLE-TYPE ROAD ADEQUATELY SERVES MODERN TRAFFIC. THE LOAD-CARRYING CAPACITY OF SUCH A ROAD DEPENDS UPON THE SUPPORTING POWER OF THE SUBGRADE AS WELL AS UPON THE THICKNESS OF THE SURFACE.

If a formula for surface thickness is founded upon a given angle of load distribution, then the size of the load contact area through which the load may be applied should necessarily be taken into account. For this reason, of the formulas cited that of Gray and those of Lelievre are the most logical. The Massachusetts formula assumes that the load is concentrated at a point; the Harger-Bonney formula assumes that it is concentrated on a line equal in length to the width of tire. The former assumption is, of course, entirely untenable whereas the latter might be a reasonable assumption for steel tires but it can scarcely be considered so for any modern tire equipment.

OTHER FORMULAS FOR COMPUTING FLEXIBLE PAVEMENT THICKNESS PRESENTED

Recently two other methods have been suggested for designing flexible pavements, one by Hawthorn and one by Housel. Although both are based upon certain theoretical conceptions of soil resistance and pressure distribution rather than upon new or original test data, in certain respects they are more complete and logical than those already enumerated.

Hawthorn's method [24] is predicated upon the assumptions that the wheel load is distributed to the subgrade through a truncated cone of the surface course and that the subgrade support under the base of the cone is uniform. Considering that the load is applied on the road surface through a circular contact area of radius a and equating the load to the subgrade support, assuming θ as the shearing or load-distributing angle, measured from the vertical, he obtained the formula

$$t=\frac{1}{\tan\theta}\sqrt{\frac{P}{\pi q}}-a$$

In which t = the thickness of surface.
P = the wheel load.
q = the unit subgrade support.

When θ is 45° this formula is exactly the same as that of Gray, namely:

$$t=0.564\sqrt{\frac{P}{q}}-a$$

In recognition of the possibility that the angle of load distribution may vary over rather wide limits, Hawthorn proposes a method for determining this angle experimentally for different types of surfacing. The method involves the measurement with soil pressure cells of the maximum value of q on the subgrade directly beneath a load applied on the surface and the substitution of this value in the above formula, solving for θ.

The use of any of the formulas enumerated for determining the thickness of flexible pavements requires, among other things, quantitative knowledge concerning the bearing capacity of the subgrade soil. With present methods of test the development of adequate knowledge of this character in the field is out of the question not only because of the time and expense involved but because of the physical impossibility of simulating with any degree of certainty the stress

[24] A Method of Designing Non-Rigid Highway Surfaces, by George Edward Hawthorn. Bulletin No. 83. University of Washington, Engineering Experiment Station, 1935.

reactions to which subgrades are subject under pavements of the flexible type.

Hawthorn offers an indirect method for developing quantitative values of soil bearing power. He developed an equation based upon the generally accepted theory that the resistance that a soil offers to displacement under sustained load depends upon its cohesion and internal friction. This equation also takes into account the added resistance to displacement that the weight of a road surface may afford. The principle of the method is much the same as that advanced by Hogentogler and Terzaghi in 1929, wherein the bearing capacity of a long narrow loaded strip was equated in terms of the two physical properties of the soil mentioned above and the secondary load adjacent to the bearing strip. It was necessary, of course, for Hawthorn to modify this method to the extent of considering tire contact areas rather than narrow loaded strips.

While this method of design might be said to be more complete than those previously described because ways and means are suggested for ascertaining the angle of load distribution through the surfacing material and the bearing capacity of the subgrade, there is considerable reason to question whether it is any more rational in principle.

In the first place, in view of what has been said about pressure distribution beneath bearing plates of different rigidity, it is extremely questionable whether the angle of load distribution can be determined within a reasonable degree of accuracy in the manner prescribed. According to Hawthorn's formula the thickness of surface varies inversely as the tangent of the angle of load distribution. This means that a change in the angle of 1 degree corresponds to a difference in road surface thickness of almost 3 percent. Emphasis is thus placed upon the importance of having or developing an accurate expression of the angle of load distribution if values of pavement thickness calculated by the prescribed method are to be considered more than merely indicative.

In the second place, as far as the method suggested for evaluating subgrade bearing capacity is concerned, there is some question as to whether present methods of test will furnish values of the angle of internal friction and unit cohesive force of different soils suitable for use in a formula such as the author has developed.

DEVELOPMENT OF THE MOST RECENT THICKNESS FORMULA OUTLINED

Housel's method [25] of flexible pavement design is premised upon the conceptions that (1) the amount of sustained pressure that a flexible road mat can distribute beyond the confines of a loaded area depends upon its ability to transmit shear on the lateral surface of the column beneath the loaded area, and (2) the maximum resistance that a subgrade material (cohesive soil) offers to displacement is a function of its shearing resistance.

Briefly the major steps in the mathematical development of his thickness formula are as follows:

1.—Equation (1) $p_z=p_0-\frac{4m_1t}{b}+w_1t$

In which p_z= the unit pressure on the subgrade beneath the loaded area on the mat.
p_0= the unit pressure applied on the surface.
m_1= the unit shearing resistance of the mat.
t= the thickness of mat.
b= the diameter of the load contact area (considered as circular).
w_1= the weight of the mat.

The quantity $\frac{4m_1t}{b}$ represents the pressure per unit of contact area that is transmitted outside the central pressure column by virtue of the resistance the surface mat offers to punching shear. This was obtained by considering that the unit pressure so transmitted is equal to the unit shearing resistance of the mat times the surface area of the central column divided by the cross sectional area of the column; i. e. $\frac{\pi btm_1}{\pi b^2/4}$. The quantity w_1t represents the weight of the surface mat, which in the equation is taken as an additional source of subgrade pressure

Specifically, equation (1) is intended to evaluate the intensity of pressure concentration which may be transmitted to the subgrade in terms of (1) size of loaded area, (2) thickness of surface mat, (3) shearing resistance of the mat material, and (4) weight of the mat.

2.—Equation (4) $p_z=4\ m_2+w_1{}^t+\frac{2m_1t}{b}$

In which p_z= the total unit bearing capacity of the subgrade.
m_2= the unit shearing resistance of the subgrade soil.
w_1= weight of mat.
t= thickness of mat.
m_1= the unit shearing resistance of mat.
b= the diameter of the load contact area on the mat.

The quantity $4m_2$ represents that part of the resistance that the subgrade soil offers to displacement as a result of its shearing resistance (p. 123, Housel's report). The quantity w_1t represents the additional resistance that the weight of the mat affords against lateral movement of the soil; and the quantity $\frac{2m_1t}{b}$ represents the shearing resistance that the mat offers against such movement. The latter quantity was developed considering b as the diameter of the load contact area, $3b$ the diameter of the subgrade pressure area and $(\pi b+3\pi b)t$ as the total shearing surface of the mat tending to resist upward movement of the soil. Thus $(\pi b+3\pi b)tm_1$ represents the total resisting force offered by the mat, which, when divided by the cross sectional area adjacent to the load contact area and within the outer circle of the subgrade pressure area, becomes $\frac{2m_1t}{b}$ or the downward-acting force of the mat per unit of area.

Equation (4) then is intended to evaluate the total unit bearing capacity p_z of the subgrade in terms of (1) the shearing resistance of the material m_2, (2) the weight of the mat w_1t and (3) the shearing resistance of the mat m_1.

3.—Equation (5) $\left(p_0=4m_2+\frac{6m_1\ t}{b}\right)$, obtained by combining equations (1) and (4), expresses the unit bearing capacity of the pavement structure in terms of

[25] Design of Flexible Surfaces, by W. S. Housel. Proceedings of the Twenty-third Annual Highway Conference. University of Michigan, 1937.

all the resisting stresses; i. e., the shearing resistance of the surface mat and the shearing resistance of the subgrade soil, and in terms of the mat thickness and the diameter of the load contact area.

QUESTIONS RAISED RELATING TO THE ABOVE FORMULA

Among the questions that might be raised concerning the above mathematical treatment of the problem are:

1. Has proper consideration been accorded the condition at the plane of contact between the flexible surface and the supporting medium? Can, for example, the pressure on a cohesive subgrade beneath a loaded area on a flexible pavement be considered as uniform? According to the test data of Dr. Press (see p. 205), the pressure transmitted to a moist loam soil through a flexible bearing plate, uniformly loaded, varied to an appreciable degree.

2. Does the quantity $4m_2$ in equation (4), which is considered the sole source of resistance that the subgrade soil offers to displacement by virtue of its ability to resist shearing stresses, take into account the size of the pressure area? It appears that this quantity is a valid expression of resistance only in case the load is considered as being applied to the soil through a narrow strip, infinite in length.

3. In evaluating the resistance, $\left(\frac{2\,m_1\,t}{b}\right)$, that a surface mat may offer against lateral or upward displacement of the subgrade adjacent to the loaded area, is it proper to consider this resistance at the outer zone of pressure influence as shearing resistance? It appears that it is a question here primarily of bending resistance.

4. Housel takes cognizance of the fact that for certain types of cohesive soil, settlement resulting from vertical compression may predominate and that as a result the surface mat may not function effectively as an added source of subgrade resistance. For this reason he reduces the quantity $\frac{6\,m_1\,t}{b}$ in equation (5) to $\frac{4\,m_1\,t}{b}$. The question arises in this connection as to whether the same arbitrary allowance should be made for all types of cohesive soils.

Earlier in this report the statement was made that adequate information at present is lacking concerning the effect and intensity of the dynamic forces that vehicles impose upon pavements of the flexible type. It is largely because of this fact that the methods of design which have been developed to date are predicated upon static load considerations. In calculating the thickness of surface with them, some sort of an arbitrary safety factor is sometimes introduced to compensate for the possible dynamic or impact effects that moving vehicles may have upon the pavement.

For example, Harger and Bonney advocate an allowance of 50 percent over and above the permissible static wheel load in computing pavement thickness with their formula [22 26]. Hawthorn, in addition to advocating the same allowance for impact, would base thickness upon values of subgrade resistance not greater than 50 percent of the ultimate strength. Both Gray and Housel contend that no allowance need be made for impact because the dynamic resistance of flexible pavements, i. e., the resistance that materials composing such pavements offer to deformation under quickly applied loads, may entirely outweigh any actual impact forces.

[26] Rational Road Design, by F. T Sheets. Engineering News-Record, vol. 114, no. 3, 1935.

SUMMARY

This report has been devoted to a digest and discussion of published material pertinent to the design of flexible pavements. It was pointed out that while our knowledge of subgrades has progressed to the point where they can be prepared more or less according to scientific principles or in such manner that they will provide reasonably uniform and constant support to road surfaces, adequate information is lacking concerning their quantitative bearing capacity, at least that type of information suitable for use in design formulas.

The question of pressure distribution was dealt with at some length. It was brought out that the intensity of pressure transmitted to flexible pavement subgrades may depend to a large extent upon the degree of rigidity of the surface mat as well as upon the character of the subgrade soil. In view of this it does not appear that we should attempt to apply our knowledge or conceptions of rigid footing stress distribution in soils directly to the problem of flexible pavement design.

Considerable space was devoted to a review of the methods of design of flexible pavements that have been formulated to date. While these methods have contributed to our understanding of the factors involved in the problem and have served to stimulate an interest in the problem generally, they are, as was pointed out, premised more upon existing conceptions of soil resistance and pressure distribution than upon any great amount of new or pertinent data. The discussion serves to emphasize the need for the development of more comprehensive test data relating directly to the problems of load-supporting capacity and pressure distribution of flexible pavements resting upon different types of subgrade soil.

Finally, the question of vehicle loads in their relation to pavement surfaces of the nonrigid type was discussed and the need for more adequate information, particularly on dynamic effects, pointed out. It is apparent that before the required thickness of a pavement can be determined by any formula the question as to what is the critical wheel load must be answered.

Specifically, the major parts of the general problem that demand first attention seem to be:

1. A study of the load-supporting and pressure-distributing ability of typical surfaces of the non-rigid type as influenced by—
    a. The magnitude of the load.
    b. The area of load application and the distribution of pressure intensity over the area.
    c. The time duration of the load.
    d. The physical characteristics of the surface course and of the subgrade.

It is probable that with suitable testing equipment much information of value could be developed from specially constructed test sections. However, the development of satisfactory pressure-measuring equipment for tests such as these is not a simple matter and an important preliminary task is the development of the necessary testing equipment.

2. The development of data that indicate more directly the safe load-supporting value of soils when subject to forces and displacements such as obtain under road surfaces of the nonrigid type. Factors that probably exert an important influence are—

a. The size of the area of applied pressure.
b. The rigidity of the surface through which the pressure is applied.
c. The effect of restraint to vertical movement around the area of applied pressure.
d. The physical characteristics of the subgrade material.

3. The determination of the relative effects of slowly applied and suddenly applied forces in order that the critical load for design purposes may be known.

It is apparent that the general problem is one of wide scope and great complexity. It is one of obvious importance. An early solution is not to be anticipated but great progress will undoubtedly be made toward one by the combined and coordinated efforts of the many research agencies now exploring this field.

THE ANGEL OF SHAVANO

The Angel of Shavano, illustrated on the cover of this issue, is an image created by converging snow-filled ravines and can be seen in early summer from U. S. Highway 650 near Salida, Colo. It rests on the dished east face of Shavano Peak, which is a 14,179-foot peak in the College Peaks Range high in the Colorado Rockies. As the snows melt away during early summer thaws, only the deeper drifts remain, creating the image of an angel with outspread wings.

PUBLICATION ON DESIGN OF CAMP STOVES AND FIREPLACES MADE AVAILABLE

A publication on camp stoves and fireplaces for recreational areas has been prepared by the Forest Service of the United States Department of Agriculture in an effort to bring together the best information available at the present time. The discussion applies primarily to the problems presented in the camps and picnic areas in the national forests; but it may apply equally well to many other types of recreational areas. It should be valuable to highway engineers who occasionally supervise the construction of recreational facilities in connection with roadside development.

The discussion ranges from the most informal picnic fireplaces and portable stoves to the most intricate masonry ovens for long-time camping. It covers automobile stoves, cooking standards, campfire circles, fireplaces with top grates or plates and with or without chimneys, combined fireplaces and stoves, multiple stoves, warming fires and shelters such as for mountaintops, and barbecue pits and ovens, as well as the lay-outs for camp units. There are right and wrong ways shown for building foundations, fireboxes, stonework, and chimneys. The materials discussed are iron, brick, concrete, stone, and sand. Special attention is given to fire hazards, fuel problems, and artistic design in fitting the fireplaces into the natural background. The book is profusely illustrated with 30 plates, each containing several sketches.

"Camp Stoves and Fireplaces" may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C., for $1.50 per copy (in buckram).

STATUS OF FEDERAL-AID HIGHWAY PROJECTS

AS OF DECEMBER 31, 1937

STATE	COMPLETED DURING CURRENT FISCAL YEAR			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	Estimated Total Cost	Federal Aid	Miles	
Alabama	$1,122,820	$551,410	64.3	$2,088,341	$1,044,170	89.2	$2,936,320	$1,468,155	132.3	$4,783,445
Arizona	1,431,770	1,042,305	72.6	1,233,292	797,498	52.1	497,850	301,159	29.1	978,847
Arkansas	2,760,421	2,757,784	183.6	1,413,140	1,409,457	86.1	23,505	23,177		2,208,501
California	6,502,940	3,601,359	147.0	5,721,259	2,948,700	93.6	3,442,246	1,910,483	55.3	448,711
Colorado	2,783,235	1,554,449	113.2	867,332	474,504	22.6	1,260,741	685,250	48.8	1,666,886
Connecticut	783,198	389,196	9.3	231,520	108,123	.8				1,513,588
Delaware	393,079	196,494	14.2	141,431	70,672	6.7	219,285	107,624	13.3	1,118,222
Florida	301,082	149,953	8.2	2,716,172	1,358,086	65.2	862,070	431,035	13.6	2,478,109
Georgia	1,920,365	944,168	109.1	4,590,292	2,295,141	209.7	2,889,994	1,444,997	126.9	3,943,310
Idaho	2,385,991	1,420,624	183.9	877,807	523,929	67.5	422,853	238,838	13.6	789,066
Illinois	9,189,422	4,535,766	256.4	5,721,961	2,856,873	167.8	4,972,000	2,373,500	82.7	1,210,163
Indiana	5,474,706	2,719,168	129.4	2,897,715	1,448,741	88.8	1,568,123	764,749	35.9	1,717,700
Iowa	6,562,611	2,971,928	210.2	4,306,510	1,919,583	127.8	2,117,085	984,450	60.0	211,327
Kansas	3,388,496	1,666,284	176.7	3,203,115	1,601,458	96.4	1,873,773	936,750	107.9	3,123,950
Kentucky	2,096,616	998,308	64.1	3,453,236	1,726,618	88.7	1,363,804	681,902	80.2	2,278,170
Louisiana	382,218	186,475	9.3	6,555,335	1,430,435	45.2	5,547,243	892,045	23.0	1,688,236
Maine	1,898,980	949,490	52.6	1,871,216	935,608	42.2	588,410	294,200	13.6	102,890
Maryland	930,330	465,145	13.4	1,808,594	902,534	28.9	460,360	230,180	.5	1,496,949
Massachusetts	3,989,577	1,994,777	19.0	2,250,345	1,125,182	4.5	182,696	91,348	.5	1,877,025
Michigan	5,969,610	2,964,646	156.9	5,918,610	2,959,805	140.5	1,648,171	749,260	25.7	48,175
Minnesota	5,726,156	2,851,531	263.1	3,029,921	1,503,716	125.1	1,881,072	930,536	84.1	1,159,140
Mississippi	1,992,300	993,411	92.4	3,846,200	1,967,890	178.3	2,205,520	1,096,860	89.7	2,575,015
Missouri	7,988,021	3,990,319	431.5	4,544,605	2,176,287	126.1	3,437,741	1,351,861	74.3	1,321,959
Montana	3,884,103	2,177,243	283.7	1,867,927	1,050,333	86.4	571,734	321,594	33.8	1,969,638
Nebraska	2,365,131	1,182,565	239.8	4,414,743	2,195,350	409.2	2,772,648	755,215	92.7	1,998,636
Nevada	2,343,933	2,020,937	106.8	621,794	536,243	61.2	168,986	142,722	6.2	670,281
New Hampshire	360,696	177,963	6.5	518,529	256,321	9.5	29,819	14,909		985,626
New Jersey	1,674,607	760,009	20.2	1,180,410	589,885	6.5	1,921,170	959,750	12.7	1,171,595
New Mexico	3,010,136	1,844,775	219.0	2,177,374	1,427,886	109.8	230,230	130,729	6.9	243,974
New York	12,570,989	5,925,156	217.9	13,590,977	6,536,060	226.9	2,673,640	1,322,177	42.6	258,061
North Carolina	3,703,171	1,848,284	286.0	4,956,705	2,307,803	194.1	2,300,553	1,113,772	106.0	1,842,485
North Dakota	1,037,450	1,037,450	186.5	1,310,220	1,289,710	77.4	494,172	494,172	48.3	2,900,901
Ohio	3,486,353	1,672,663	47.4	9,209,649	4,570,066	100.5	1,735,295	868,083	20.6	4,993,796
Oklahoma	2,681,973	1,406,287	120.5	2,574,355	1,330,599	104.6	1,772,959	899,587	83.5	3,045,669
Oregon	3,616,277	2,138,059	126.9	1,521,346	927,815	64.3	863,711	488,280	35.5	729,582
Pennsylvania	11,070,339	5,506,738	155.6	6,741,086	3,351,103	92.1	3,557,147	1,777,536	64.2	2,238,829
Rhode Island	824,252	403,311	7.1	1,077,910	538,955	14.0	8,930	4,465		758,165
South Carolina	2,798,904	1,182,403	231.4	5,028,250	2,109,405	211.9	1,762,019	765,335	86.1	799,561
South Dakota	2,462,981	1,392,121	247.0	1,621,376	896,530	173.5	443,673	246,033	58.3	3,012,577
Tennessee	1,428,656	713,399	61.1	1,725,904	862,952	49.0	1,579,280	789,640	46.5	4,177,526
Texas	9,569,063	4,777,227	682.6	9,700,980	4,833,724	440.6	5,252,642	2,518,629	312.9	4,220,909
Utah	1,205,372	861,169	115.2	910,090	646,212	75.2	34,070	24,390	.5	1,080,148
Vermont	1,010,512	489,925	29.2	1,679,730	739,094	43.1	6,730	3,169		61,544
Virginia	2,627,752	1,313,876	124.1	2,587,202	1,247,525	65.3	3,026,407	1,509,504	89.5	870,232
Washington	1,820,861	944,478	73.1	3,249,031	1,704,312	39.9	560,860	294,700	7.9	550,674
West Virginia	901,295	455,248	24.3	1,576,571	787,379	42.8	635,792	514,831	17.5	1,935,697
Wisconsin	7,916,680	3,795,535	260.3	4,562,401	2,096,577	101.9	289,791	133,900	10.1	1,122,102
Wyoming	2,460,514	1,502,528	255.6	1,290,663	778,272	142.5	199,109	122,996	17.1	123,808
District of Columbia										
Hawaii	537,013	260,604	8.9	521,869	257,937	9.0	325,610	160,750	4.8	1,148,917
Puerto Rico				791,809	393,925	16.0	286,750	143,375	4.3	87,700
TOTALS	163,342,957	85,684,943	6,917.1	156,296,850	77,846,983	4,921.0	73,904,589	34,508,602	2,319.5	81,738,017

CURRENT STATUS OF UNITED STATES WORKS PROGRAM HIGHWAY PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF DECEMBER 31, 1937

STATE	APPORTIONMENT	COMPLETED			UNDER CONSTRUCTION			APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
		Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	Estimated Total Cost	Works Program Funds	Miles	
Alabama	$4,151,115	$3,922,906	$3,874,971	136.9	$250,100	$243,478	7.8				$32,666
Arizona	2,569,841	3,156,644	2,505,062	193.7	38,548	38,548					26,230
Arkansas	3,352,061	3,149,006	3,121,666	350.5	181,216	180,523	9.8				49,872
California	7,747,928	7,954,424	7,541,007	263.9	145,356	145,356					61,566
Colorado	3,395,263	2,382,800	2,290,828	99.4	89,597	89,596	6.0	$8,200	$8,200		1,006,639
Connecticut	1,418,709	1,188,498	1,100,096	17.3	232,031	206,330	4.5	124,130	64,435	0.2	47,848
Delaware	900,310	861,217	835,485	62.6	22,850	22,850	4.0	26,712	26,712	4.4	15,263
Florida	2,597,144	2,603,553	2,529,126	99.1	38,957	38,957					29,061
Georgia	4,988,967	1,907,300	1,865,928	109.2	2,298,324	2,029,944	105.6	442,460	442,460	29.6	650,634
Idaho	2,222,747	2,273,614	2,167,698	185.9	33,341	33,341					21,707
Illinois	8,694,009	8,123,932	7,877,907	465.0	685,010	685,010	23.2				131,092
Indiana	4,941,255	5,169,692	4,845,920	238.4	49,000	49,000					46,335
Iowa	4,991,664	5,237,605	4,885,935	528.3	105,902	104,865	.3				864
Kansas	4,994,975	4,728,602	4,658,563	370.6	242,985	240,813	20.1	51,590	51,590	2.1	44,010
Kentucky	3,726,271	3,596,827	3,430,251	355.0	271,221	271,221	3.5				24,799
Louisiana	2,890,429	2,822,001	2,524,286	166.2	300,666	240,049	1.6	97,087	97,070	10.4	29,024
Maine	1,676,799	1,630,328	1,616,413	74.4	60,849	58,250	1.7				2,136
Maryland	1,750,738	773,435	766,648	27.2	467,536	467,536	10.0	168,198	134,366	4.3	382,189
Massachusetts	3,262,885	2,191,459	2,191,383	18.0	829,930	439,160	.4	1,136,726	568,363	.8	63,979
Michigan	6,301,414	6,573,146	5,950,255	288.6	284,921	284,921	3.4	230,438	63,746	.3	2,492
Minnesota	5,277,145	6,403,162	5,184,516	896.0	96,799	88,962	5.9				3,667
Mississippi	3,457,552	2,991,155	2,986,533	209.7	395,446	394,406	25.9	10,800	10,800	.6	65,813
Missouri	6,012,652	5,290,224	5,140,206	776.9	790,784	736,082	.7	34,391	32,294		104,070
Montana	3,676,416	3,597,353	3,535,614	200.7	95,385	95,385	.1	8,462	8,462		36,955
Nebraska	3,870,739	3,437,332	3,327,793	362.3	445,830	445,830	8.3	70,270	70,270	1.8	26,846
Nevada	2,243,074	2,301,828	2,195,115	110.0	84,970	38,146	1.7				9,813
New Hampshire	945,225	875,636	843,253	37.7	121,092	101,301	5.7				671
New Jersey	3,129,805	1,281,435	1,261,330	27.8	1,832,989	1,832,989	7.6	34,468	34,468		1,018
New Mexico	2,871,397	2,811,536	2,806,370	213.7	43,071	43,071		14,681	12,196		9,760
New York	11,046,377	10,741,839	10,276,419	170.0	316,300	276,300	1.9	68,000	68,000	.2	425,658
North Carolina	4,720,173	4,521,721	4,453,105	277.2	194,791	194,791	13.5	37,900	37,900	.5	34,377
North Dakota	2,867,245	2,491,800	2,448,886	378.4	107,799	107,799	1.2	286,285	286,285	36.0	24,275
Ohio	7,670,815	6,958,421	6,842,574	287.9	730,632	724,632	8.8	30,200	30,200	1.9	73,409
Oklahoma	4,580,670	4,542,968	4,310,604	400.5	251,970	251,970	7.9	8,800	5,000	.1	13,096
Oregon	3,038,642	3,216,548	2,950,184	164.6	45,580	45,580		11,846	11,846	1.0	31,032
Pennsylvania	9,347,797	6,543,808	6,233,396	253.7	3,084,682	2,676,346	28.3	368,646	273,316	3.9	164,739
Rhode Island	989,208	1,111,600	989,136	18.8							72
South Carolina	2,702,012	2,290,110	2,110,868	224.6	617,029	545,752	24.9	9,664	9,664	1.5	35,728
South Dakota	2,976,454	2,689,680	2,685,957	482.6	270,437	270,437	22.0				20,060
Tennessee	4,192,460	3,432,415	3,381,237	134.3	778,283	778,283	16.5	35,710	22,060	2.6	10,881
Texas	11,989,350	12,587,020	11,525,419	1,105.8	458,571	346,058	11.9	83,337	83,100	7.2	34,773
Utah	2,067,154	2,150,682	1,929,726	208.2	112,055	112,055	.1				25,372
Vermont	924,306	1,060,294	913,206	23.2	11,100	11,100					
Virginia	3,652,667	3,365,922	3,261,799	989.0	172,141	168,844	14.2				222,024
Washington	3,026,161	3,316,804	2,940,422	164.3	65,824	65,824	.7				19,915
West Virginia	2,231,412	1,976,515	1,880,973	81.0	375,022	317,639	14.5	32,800	32,800	4.9	
Wisconsin	4,823,884	5,231,164	4,729,389	343.4	94,268	93,900	.3				595
Wyoming	2,219,155	2,170,832	2,165,171	152.4	33,287	33,287					20,697
District of Columbia	949,496	950,000	949,496	8.8							
Hawaii	926,033	678,560	655,700	10.4	277,293	215,689	7.0	62,530	54,644	.6	
TOTALS	195,000,000	181,265,353	171,493,825	12,764.7	18,531,770	16,882,206	431.5	3,494,331	2,540,247	114.9	4,083,722

CURRENT STATUS OF UNITED STATES WORKS PROGRAM GRADE CROSSING PROJECTS

(AS PROVIDED BY THE EMERGENCY RELIEF APPROPRIATION ACT OF 1935)

AS OF DECEMBER 31, 1937

STATE	APPORTIONMENT	COMPLETED		NUMBER			UNDER CONSTRUCTION		NUMBER			APPROVED FOR CONSTRUCTION		NUMBER			BALANCE OF FUNDS AVAILABLE FOR PROGRAMMED PROJECTS
		Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	Estimated Total Cost	Works Program Funds	Grade Crossings Eliminated by Separation or Relocation	Grade Crossing Structures Reconstructed	Grade Crossings Protected by Signals or Otherwise	
Alabama	$4,034,617	$3,554,270	$3,538,941	47	1	12	$378,519	$378,519	2			$175,300	$109,000	4			$8,157
Arizona	1,256,099	1,216,505	1,170,445	14		3	85,121	62,712	1		1	2,280	2,280			1	20,662
Arkansas	3,574,060	2,825,257	2,817,988	51	6	7	687,340	686,635	5		17	23,923	23,923			9	45,514
California	7,486,362	7,210,651	7,023,934	46	8		414,005	414,004	1			10,000	10,000	5			38,424
Colorado	2,631,567	2,262,520	2,193,165	27	1	8	437,794	437,794	3	2	13						608
Connecticut	1,712,684	479,557	479,463	3	1	1	1,157,071	1,135,710	7								97,511
Delaware	418,239	130,000	130,000	1			279,052	279,052	2								9,187
Florida	2,827,883	2,408,845	2,381,150	30	5	2	119,018	119,018	1			136,010	136,010			74	191,705
Georgia	4,895,949	702,989	701,485	16	5	10	1,357,729	1,357,729	22	8	7	939,100	939,100	12	2	35	1,897,635
Idaho	1,674,479	1,392,801	1,366,439	20	3	12	252,696	252,696	2		6	4,261	4,261			3	51,083
Illinois	10,307,184	8,803,088	8,675,516	65	8		1,500,134	1,493,730	9			101,000	101,000	2			36,938
Indiana	5,111,096	4,370,132	4,248,088	39	13		857,447	857,447	3		162						5,561
Iowa	5,600,679	4,589,282	4,493,882	98	9	8	1,092,875	1,089,000	8								17,797
Kansas	5,246,258	3,951,273	3,929,165	54		5	1,273,119	1,253,704	4	1		115,024	22,020	2		3	41,369
Kentucky	3,672,387	1,359,956	1,341,033	19	5		1,984,219	1,694,487	5	6		612,579	612,579	3	1		24,288
Louisiana	3,213,467	1,466,944	1,466,936	15	1		982,285	982,265	10	1		649,599	600,110	4	1		164,155
Maine	1,426,861	1,266,773	1,263,012	19	1	4	160,788	142,540	1	1							21,309
Maryland	2,061,751	660,619	660,481	5	3	18	865,674	815,674	5	2	6	292,562	270,093	1	1	6	315,503
Massachusetts	4,210,833	2,605,349	2,602,919	21	4		1,189,410	1,189,410	5			249,991	249,991	1			168,513
Michigan	6,765,197	6,872,919	6,563,144	44	8		101,477	101,477				175,500	84,230	1	1		16,346
Minnesota	5,395,441	4,765,523	4,654,827	82	13	50	676,480	670,430	4								70,184
Mississippi	3,241,475	2,210,035	2,204,881	49	4	8	524,453	524,453	6	3	3	71,900	71,900	2		12	440,241
Missouri	6,142,153	4,276,951	4,106,511	39	1		2,029,178	2,029,178	10		1	1,650	1,650			1	4,814
Montana	2,722,327	2,580,711	2,530,870	37	7		245,576	185,931	1	1							5,526
Nebraska	3,556,441	2,896,387	2,852,853	76	3	21	470,813	470,813	5		1	199,683	199,683	3		2	33,093
Nevada	887,260	877,030	845,455	8	3		13,308	13,308				3,630	3,630			5	24,867
New Hampshire	822,484	791,275	791,208	9	4	6	53,297	29,170	1			2,106	2,106			1	
New Jersey	3,983,826	3,058,833	3,045,868	20	5	1	831,570	831,570	4	4		44,730	44,730		1		61,658
New Mexico	1,725,286	1,700,977	1,694,089	19	1		25,879	25,879									5,317
New York	13,577,139	10,893,644	10,607,445	34	42		2,683,270	2,683,270	11	7		94,000	94,000				192,474
North Carolina	4,823,958	3,519,978	3,499,838	48	18		1,199,009	1,199,009	14		115						125,110
North Dakota	3,207,473	2,817,411	2,813,288	56	4		389,012	389,012		1							5,173
Ohio	8,439,897	2,494,830	2,366,019	19	6	2	5,506,734	5,038,588	28	2	8	843,940	828,940	12		4	206,351
Oklahoma	5,004,711	3,667,115	3,653,002	57	9	13	1,353,584	1,220,484	8	3	8	64,150	64,150			20	67,075
Oregon	2,334,204	2,329,684	2,242,111	16	6	2	74,215	74,215	1								17,878
Pennsylvania	11,483,613	7,730,138	7,217,210	65	18	9	4,195,716	3,828,728	21	5		150,473	150,473	5			287,202
Rhode Island	699,691	701,008	695,039	4	3												4,652
South Carolina	3,059,956	1,662,668	1,642,405	32	11	25	916,922	909,827	14	4	11	176,367	176,367	1	1	12	331,358
South Dakota	3,249,086	2,858,402	2,857,001	59	6	53	175,186	175,186	6			269,350	210,393	17			6,506
Tennessee	3,903,979	1,475,878	1,467,197	27	3	29	2,070,150	2,070,150	18	1	1	130,360	130,360	1		10	236,272
Texas	10,855,982	9,807,750	9,795,560	125	14	82	555,744	555,744	3	1	13	167,019	167,019			54	337,659
Utah	1,230,763	1,203,470	1,196,574	17	1	1	18,461	18,461									15,728
Vermont	729,857	748,907	703,707	10	7	18	14,100	14,100			2						12,050
Virginia	3,774,287	2,742,102	2,605,579	43	16	21	1,117,828	1,111,203	9	4	1	33,140	33,140		1	2	24,365
Washington	3,095,041	2,719,915	2,696,744	22	11	11	368,494	368,069	1	1							30,228
West Virginia	2,677,937	1,071,821	1,069,853	10	2	5	1,525,782	1,525,281	16	1	1	78,855	78,855	2		1	3,948
Wisconsin	5,022,683	4,558,834	4,522,667	37	6	2	398,588	398,385		1	11	105,746	38,299			21	63,332
Wyoming	1,360,841	1,220,946	1,203,948	13			111,212	111,212	1								45,681
Dist. of Columbia	410,804	417,779	410,804	3													
Hawaii	453,703	284,891	284,005	3			226,162	169,698	2								
TOTALS	196,000,000	146,214,623	143,323,744	1673	306	449	42,946,496	41,384,957	280	60	388	5,924,228	5,460,292	78	9	276	5,831,007

U. S. GOVERNMENT PRINTING OFFICE: 1938

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PUBLICATIONS of the BUREAU OF PUBLIC ROADS

Any of the following publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. As his office is not connected with the Department and as the Department does not sell publications, please send no remittance to the United States Department of Agriculture.

ANNUAL REPORTS

Report of the Chief of the Bureau of Public Roads, 1931. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1933. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1934. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1935. 5 cents.

Report of the Chief of the Bureau of Public Roads, 1936. 10 cents.

Report of the Chief of the Bureau of Public Roads, 1937. 10 cents.

DEPARTMENT BULLETINS

No. 1279D . . Rural Highway Mileage, Income, and Expenditures, 1921 and 1922. 15 cents.

No. 1486D . . Highway Bridge Location. 15 cents.

TECHNICAL BULLETINS

No. 55T . . . Highway Bridge Surveys. 20 cents.

No. 265T . . . Electrical Equipment on Movable Bridges. 35 cents.

MISCELLANEOUS PUBLICATIONS

No. 76MP . . The Results of Physical Tests of Road-Building Rock. 25 cents.

No. 191MP. Roadside Improvement. 10 cents.

No. 272MP. Construction of Private Driveways. 10 cents.

No. 279MP. Bibliography on Highway Lighting. 5 cents.

The Taxation of Motor Vehicles in 1932. 35 cents.

Guides to Traffic Safety. 10 cents.

Federal Legislation and Rules and Regulations Relating to Highway Construction. 15 cents.

An Economic and Statistical Analysis of Highway-Construction Expenditures. 15 cents.

Highway Bond Calculations. 10 cents.

Single copies of the following publications may be obtained from the Bureau of Public Roads upon request. They cannot be purchased from the Superintendent of Documents.

SEPARATE REPRINT FROM THE YEARBOOK

No. 1036Y . . Road Work on Farm Outlets Needs Skill and Right Equipment.

TRANSPORTATION SURVEY REPORTS

Report of a Survey of Transportation on the State Highway System of Ohio (1927).

Report of a Survey of Transportation on the State Highways of Vermont (1927).

Report of a Survey of Transportation on the State Highways of New Hampshire (1927).

Report of a Plan of Highway Improvement in the Regional Area of Cleveland, Ohio (1928).

Report of a Survey of Transportation on the State Highways of Pennsylvania (1928).

Report of a Survey of Traffic on the Federal-Aid Highway Systems of Eleven Western States (1930).

UNIFORM VEHICLE CODE

Act I.—Uniform Motor Vehicle Administration, Registration, Certificate of Title, and Antitheft Act.

Act II.—Uniform Motor Vehicle Operators' and Chauffeurs' License Act.

Act III.—Uniform Motor Vehicle Civil Liability Act.

Act IV.—Uniform Motor Vehicle Safety Responsibility Act.

Act V.—Uniform Act Regulating Traffic on Highways.

Model Traffic Ordinances.

A complete list of the publications of the Bureau of Public Roads, classified according to subject and including the more important articles in Public Roads, may be obtained upon request addressed to the U. S. Bureau of Public Roads, Willard Building, Washington, D. C.

CURRENT STATUS OF UNITED STATES PUBLIC WORKS ROAD CONSTRUCTION

AS PROVIDED BY SECTION 204 OF THE NATIONAL INDUSTRIAL RECOVERY ACT (1934 FUNDS) AND BY THE ACT OF JUNE 18, 1934 (1935 FUNDS)

AS OF DECEMBER 31, 1937

STATE	APPORTIONMENTS		COMPLETED				UNDER CONSTRUCTION				APPROVED FOR CONSTRUCTION			BALANCE OF FUNDS AVAILABLE FOR PROGRAMED PROJECTS	
	Sec. 204 of the Act of June 16, 1933 (1934 Fund)	Act of June 18, 1934 (1935 Fund)	Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	Estimated Total Cost	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds	Mileage	1934 Public Works Funds	1935 Public Works Funds
Alabama	$8,370,133	$4,259,842	$15,820,902	$8,310,690	$3,884,269	772.7	$72,922	$55,922	$17,000	4.0		$285,822	1.5	$3,521	$72,751
Arizona	5,211,960	2,641,935	9,036,132	5,211,960	2,616,561	537.0	19,573		19,573						5,801
Arkansas	6,748,335	3,428,049	11,131,031	6,747,820	3,412,141	637.3	11,500		11,500			3,000		515	1,408
California	15,607,354	7,932,206	30,610,401	15,607,354	7,796,202	763.9	114,585		114,383						21,621
Colorado	6,874,530	3,486,006	11,268,935	6,874,530	3,463,635	633.2	11,000		11,000						11,371
Connecticut	2,865,740	1,454,868	4,621,972	2,814,446	1,390,242	74.4	119,440	47,854	60,759	1.1				3,440	3,866
Delaware	1,819,088	923,395	2,791,041	1,819,088	923,395	128.9									
Florida	5,231,834	2,661,343	9,164,769	5,175,534	2,529,961	309.6	174,220	56,300	117,920	.5					13,462
Georgia	10,091,185	5,113,491	14,386,733	9,537,910	3,906,027	828.3	667,153	179,131	488,022	13.7	$312,513	461,598	10.6	61,632	257,844
Idaho	4,486,249	2,277,486	7,184,172	4,486,249	2,243,324	503.4	34,162		34,162						
Illinois	17,570,770	8,921,401	26,903,647	17,504,187	8,095,985	750.8	819,204		784,944	4.8		2,400	.8	66,583	38,072
Indiana	10,037,843	5,088,963	15,816,085	10,017,034	4,902,607	485.1	3,000		3,000			90,228	.9	20,809	93,129
Iowa	10,055,660	5,118,361	15,797,954	10,055,660	5,118,361	1,227.3									
Kansas	10,089,604	5,117,675	15,539,816	10,088,842	5,096,436	1,145.4						20,885	.2	761	354
Kentucky	7,517,359	3,818,311	12,227,767	7,480,082	3,769,850	814.7	32,565		32,565	.8	11,306	3,982		25,971	11,915
Louisiana	5,828,591	2,963,932	9,466,082	5,776,336	2,837,706	272.2	83,804		83,799	5.1				52,255	42,427
Maine	3,369,917	1,711,586	5,328,990	3,363,367	1,702,679	195.0						8,644		6,550	262
Maryland	3,564,527	1,810,058	5,735,982	3,471,009	1,111,390	153.7	547,475	59,747	482,208	7.4	33,770	103,930	1.8		112,530
Massachusetts	6,597,100	3,350,474	10,005,946	6,550,778	2,686,717	115.4	492,880		492,880	.1		91,944	.1	46,322	78,934
Michigan	12,736,227	6,452,568	20,880,502	12,736,227	6,355,780	768.5	96,788		96,788						
Minnesota	10,656,569	5,425,551	16,359,188	10,559,762	4,957,493	1,648.0	534,741	67,612	375,923	2.0				29,195	92,135
Mississippi	6,978,675	3,540,227	13,123,933	6,780,814	3,312,455	725.2	353,584	162,667	188,783	19.5				35,194	38,988
Missouri	12,180,306	6,173,740	18,990,709	12,116,921	5,837,130	1,447.3	283,560		283,560	.3				63,385	53,050
Montana	7,439,748	3,769,734	11,760,785	7,404,944	3,655,149	1,058.4	128,470	34,791	93,679	.2				12	20,906
Nebraska	7,828,961	3,964,364	13,182,736	7,828,961	3,917,425	1,055.2	39,755		39,755	.4					7,184
Nevada	4,545,917	2,302,356	7,074,562	4,545,917	2,265,770	758.8	21,979		21,979			11,302	1.7		3,305
New Hampshire	1,909,839	969,462	3,007,927	1,904,951	955,186	78.3					4,889	14,276			
New Jersey	6,346,039	3,220,879	10,314,432	6,265,478	3,074,953	97.0					58,170	47,500		22,391	98,426
New Mexico	5,792,935	2,941,700	8,909,776	5,748,150	2,917,944	750.0	55,585	44,785	10,800	1.2		2,695			10,261
New York	22,330,101	11,327,921	40,575,804	22,224,878	11,002,926	825.1	192,932	6,831	59,900	.1	27,881	115,400	.2	70,511	149,695
North Carolina	9,522,293	4,840,941	15,506,637	9,508,881	4,764,367	1,398.1	67,907		67,907	.3	5,960	8,200		7,452	466
North Dakota	5,804,448	2,938,967	9,070,516	5,729,310	2,545,435	2,170.3	1,681		1,681			332,106	15.6	75,138	59,745
Ohio	15,484,592	7,865,012	25,093,803	15,480,362	7,667,565	800.3	117,975		117,975					4,230	79,472
Oklahoma	9,216,798	4,685,180	14,788,739	9,214,165	4,454,062	806.6	227,954		227,954	.4				2,633	3,164
Oregon	6,106,896	3,097,814	10,051,231	6,101,165	2,999,201	469.4	46,467		46,467			35,000	.2	5,731	17,146
Pennsylvania	18,891,004	9,590,788	30,053,597	18,728,767	9,275,971	1,063.8	369,647	102,810	223,581	7.0				59,427	91,236
Rhode Island	1,998,708	1,014,572	3,150,270	1,998,708	1,012,094	89.1	2,478		2,478						
South Carolina	5,459,165	2,770,954	8,332,223	5,367,552	2,602,838	634.3	213,632	60,363	145,536	3.0				31,250	22,581
South Dakota	6,011,479	3,047,643	9,533,537	5,984,519	2,965,938	1,622.3	73,081		68,261	6.0	25,810	6,540	13.3	1,150	6,904
Tennessee	8,492,619	4,302,991	13,922,660	8,492,551	4,300,325	504.3								68	2,666
Texas	24,244,024	12,291,253	38,027,636	24,192,596	11,899,635	2,782.1	358,592	2,797	355,794	.4	40,268	1,952	1.0	8,363	33,872
Utah	4,194,708	2,132,691	7,461,635	4,194,708	2,132,691	590.9									
Vermont	1,867,573	948,007	3,181,483	1,867,573	948,007	141.0									
Virginia	7,416,757	3,765,387	11,951,109	7,366,684	3,685,487	671.6	109,038	18,439	51,176	2.4	1,500	10,000		30,134	18,725
Washington	6,115,867	3,106,412	9,408,337	6,112,042	3,018,659	303.0	85,353	3,825	74,069	1.2		5,192	.3		8,491
West Virginia	4,474,234	2,280,335	6,695,731	4,308,274	2,014,748	216.4	150,851	54,892	95,960	5.7		154,939	1.6	111,069	14,688
Wisconsin	9,724,881	4,941,837	15,457,804	9,724,881	4,871,807	619.6	40,860		40,860			14,200			14,970
Wyoming	4,501,327	2,287,712	6,954,439	4,500,651	2,244,357	1,052.2	17,900		17,900	.6		570		676	24,885
District of Columbia	1,918,469	973,842	2,892,447	1,918,469	973,842	22.3									
Hawaii	1,871,062	949,778	3,338,323	1,857,812	904,994	55.9	14,000		14,000		13,250				30,784
TOTALS	394,000,000	200,000,000	641,893,868	391,659,549	191,021,722	35,573.6	6,808,293	958,766	5,476,481	88.2	535,317	1,832,305	49.8	846,368	1,669,492